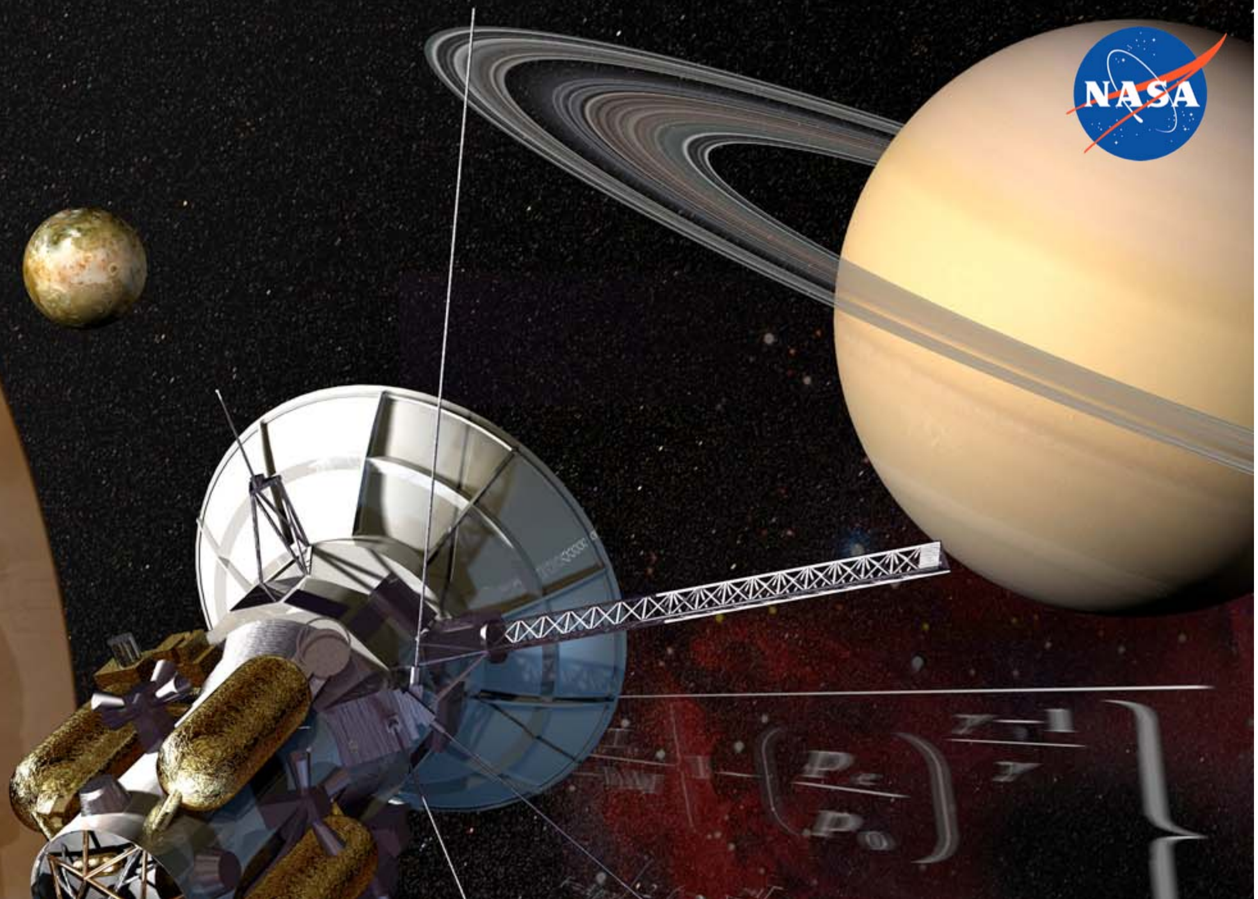
Advanced Chemical Propulsion



In Space Propulsion Technology Project
NASA Marshall Space Flight Center
Leslie Alexander, Jr

Earth Science Technology Conference 2006
June 27-29, 2006

ISPT Advanced Chemical Propulsion (ACP)

Technology Objectives and Benefits

- Develop evolutionary improvements in chemical propulsion system performance that yield near-term products and directly impact payload mass fraction and cost.
  - Resulting in greater science
  - Producing higher performance than SOA chemical systems
  - Increasing the reliability of propulsion systems

Focus areas

- Lightweight / optimized components - component, subsystem, and manufacturing technologies that offer measurable system level benefits
- Advanced propellants - evaluation of high-energy storable propellants with enhanced performance for in-space application

ISPT ACP Task Areas

Lightweight/Optimized Components Tasks

- High Temperature Storable Bipropellant Engines
  - Performance optimization of existing storable bipropellant engine designs and demonstration of increased Isp >335s by leveraging high temperature thrust chamber material potential
- Ultra-lightweight Tank Technology (ULTT)
  - Optimization of COPVs to decrease the mass of propellant and pressurant tanks.
  - Acceptance / margin testing to increase design allowables and reduce risk

ISPT ACP Task Areas

Lightweight/Optimized Components Tasks (cont.)

- High Temperature Thrust Chamber Assembly (TCA) Materials
  - Investigation of materials and manufacturing processes, e.g. Vacuum Plasma Spray (VPS), to provide high temperature options for TCAs
- Active Pressurization & Mixture Ratio Control
  - Initial laboratory demonstration using non-hazardous fluids to simulate a small, deep space, pressure-fed propulsion system
  - Investigation to determine the accuracy of critical sensor technology in at the component and subsystem level

Advanced Propellants Tasks

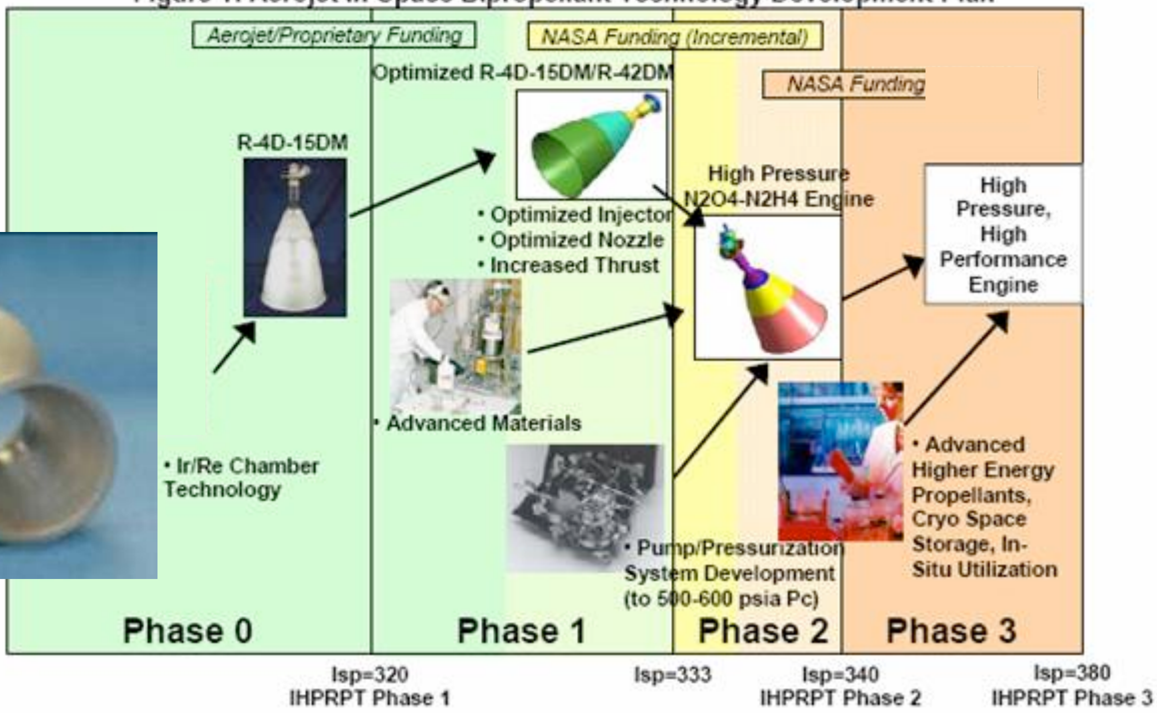
- Advanced Ionic Monopropellants
  - Assessment of high performance monoprop potential through laboratory test and simulation

High Temperature Storable Bipropellant Engines

♦ Objective

- Investigation of high temperature materials and thrust chamber manufacturing processes, such as VPS and Electro-form
- Optimization of high performance storable bipropellant engine (hot rocket)
  - Higher performance: >335s I_{sp} for NTO/N2H4 and >330s I_{sp} for NTO/MMH
  - Lower manufacturing cost with improved producibility and reliability
  - 3-10 yr mission life with >1hour operating time
- Hot-fire test demonstration to reduce risk and facilitate transition directly to in-space product line

Figure 1: Aerojet In-Space Bipropellant Technology Development Plan



High Temperature Storable Bipropellant Engines

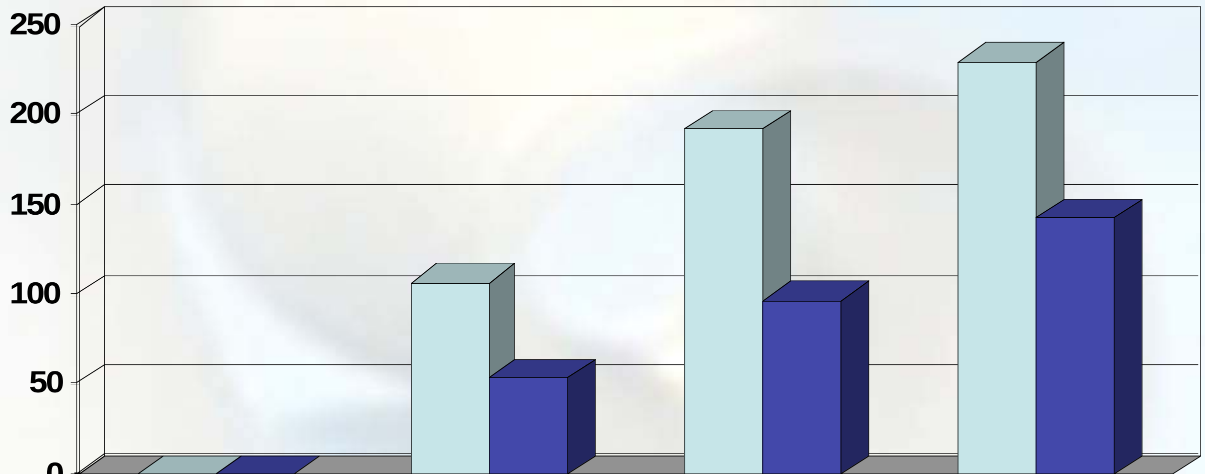
- Provide benefit for applications with medium to high ΔV and high reliability requirements
  - NASA robotic missions
  - Outer planet orbiters
  - Commercial missions such as apogee insertion of GEO COMSATs

Figure 2: Mass Savings Achievable for Europa Orbiter and GEO with High Performance, Storable Biprop Engines

Sizing Assumptions:

Europa Orbiter
- 254 lbm (115kg) to Europa Orbit
- ΔV = 18045 ft/s (5500 m/s)

GEO COMSAT
- 4513 lbm (2050 kg) to GEO
- ΔV = 6234 ft/s (1900 m/s)



	SOA Biprop (NTO/MMH)		SOA Dual Mode (NTO/N2H4)		Optimized Dual Mode (NTO/MMH)		Optimized High Pressure Dual Mode (NTO/N2H4)	
Isp, lbf-sec/lbm	320	320	327	327	330	330	335	335
Total Propellant Mass, lbm	1552	1706	1652	1657	1629	1637	1590	1602
Mass Savings, lbm	0	0	54	49	77	69	116	104
Percent Savings, %	0.0	0.0	3.2	2.8	4.5	4.1	6.8	6.1

Ultra-lightweight Tank Technology

♦ Objectives

- Decrease the mass of propellant and pressurant tanks through the development of ultra-lightweight and lightweight propellant and pressurant tank technology for missions not requiring positive expulsion of propellants
- Develop a stress-rupture properties/design database that will significantly increase the allowable design stress for propellant and pressurant tanks
- Significantly reduce the tank and propulsion system dry mass for large science missions

T-1000 lightweight tank

Ultra-lightweight Tank Technology

- Status
  - Ultralight 16-in diameter aluminum lined tanks (COPVs) with a 2 kg dry mass and 30 kg capacity for N_2H_4, have been developed at JPL for MER [similar monolithic titanium MER tank mass - 5.8 kg]
  - Non-destructive inspection methodology (such as the use of ultrasonics and sheerography) established to raise the technology maturation readiness level
  - Investigated new materials and manufacturing methods
- Ongoing
  - Validation testing of ultra-lightweight MER tanks
  - Stress-rupture testing and data acquisition
  - New tank designs and ultra-lightweight applications
    - Xe propellant tanks
    - Cryogenic propellants
    - Diaphragm and linerless tanks

Chemically etched aluminum liner

PMD

PBO/epoxy composite winding

Ultra-lightweight Tank Technology (ULTT)

PI: NASA-JPL

Co I(s): NASA/MSFC, Carleton PTD, PSI, Luxfer

MER tank
5 mil aluminum liner
Dry mass – 2 kg

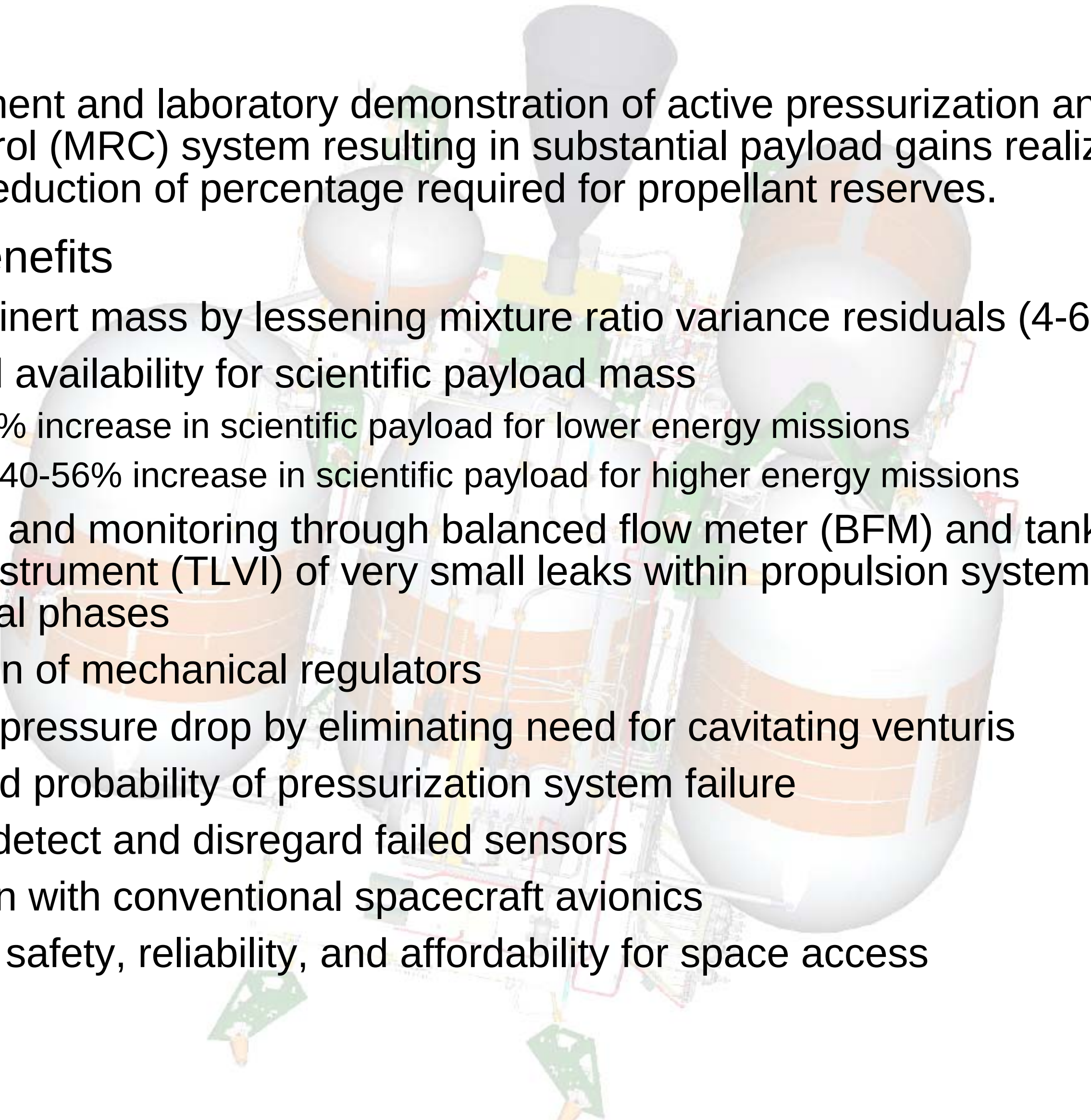
Rupture test banks

Ultra-lightweight Propellant Tanks

- **Welded liners are required for ultralight propellant tanks to allow for PMD installation, but these welds present a significant technology challenge**
  - During manufacture of ultralight hydrazine tanks for the MER program, there was a drop-out rate of 50% of liners due to indications in the TIG welds performed
- **Three ultralight tanks were successfully manufactured for the MER program. Validation testing was conducted as a part of the FY06 Ultralight Tank Technology Development Task for the ISP Program**
  - One of these three ultralight tanks was successfully tested, but two developed leaks during the test sequence
  - These tanks are scheduled to be examined, but it is currently suspected that the leaks are in the welds
- **These weld anomalies during manufacture (and possibly validation testing) point to a need for further weld technology development to arrive at TRL 6 for the technology to be infused into flight projects**




Active Pressurization and Mixture Ratio Control

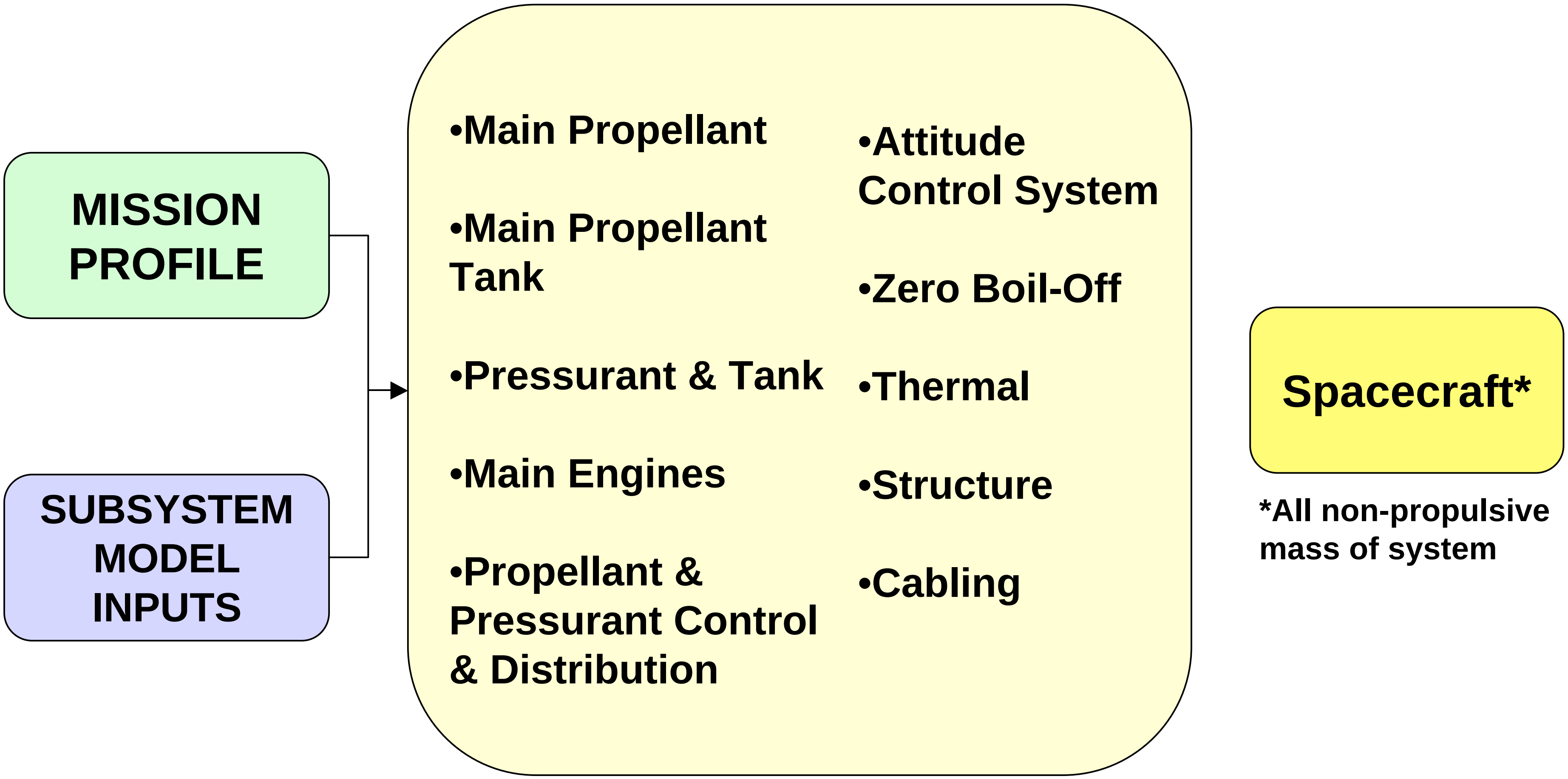


- Objective
  - Development and laboratory demonstration of active pressurization and mixture ratio control (MRC) system resulting in substantial payload gains realized through reduction of percentage required for propellant reserves.
- Potential Benefits
  - Reduced inert mass by lessening mixture ratio variance residuals (4-6%)
  - Increased availability for scientific payload mass
    - 10-15% increase in scientific payload for lower energy missions
    - Up to 40-56% increase in scientific payload for higher energy missions
  - Detection and monitoring through balanced flow meter (BFM) and tank liquid volume instrument (TLVI) of very small leaks within propulsion system during all operational phases
  - Elimination of mechanical regulators
  - Reduced pressure drop by eliminating need for cavitating venturis
  - Decreased probability of pressurization system failure
  - Ability to detect and disregard failed sensors
  - Integration with conventional spacecraft avionics
  - Improved safety, reliability, and affordability for space access

Active Pressurization and Mixture Ratio Control

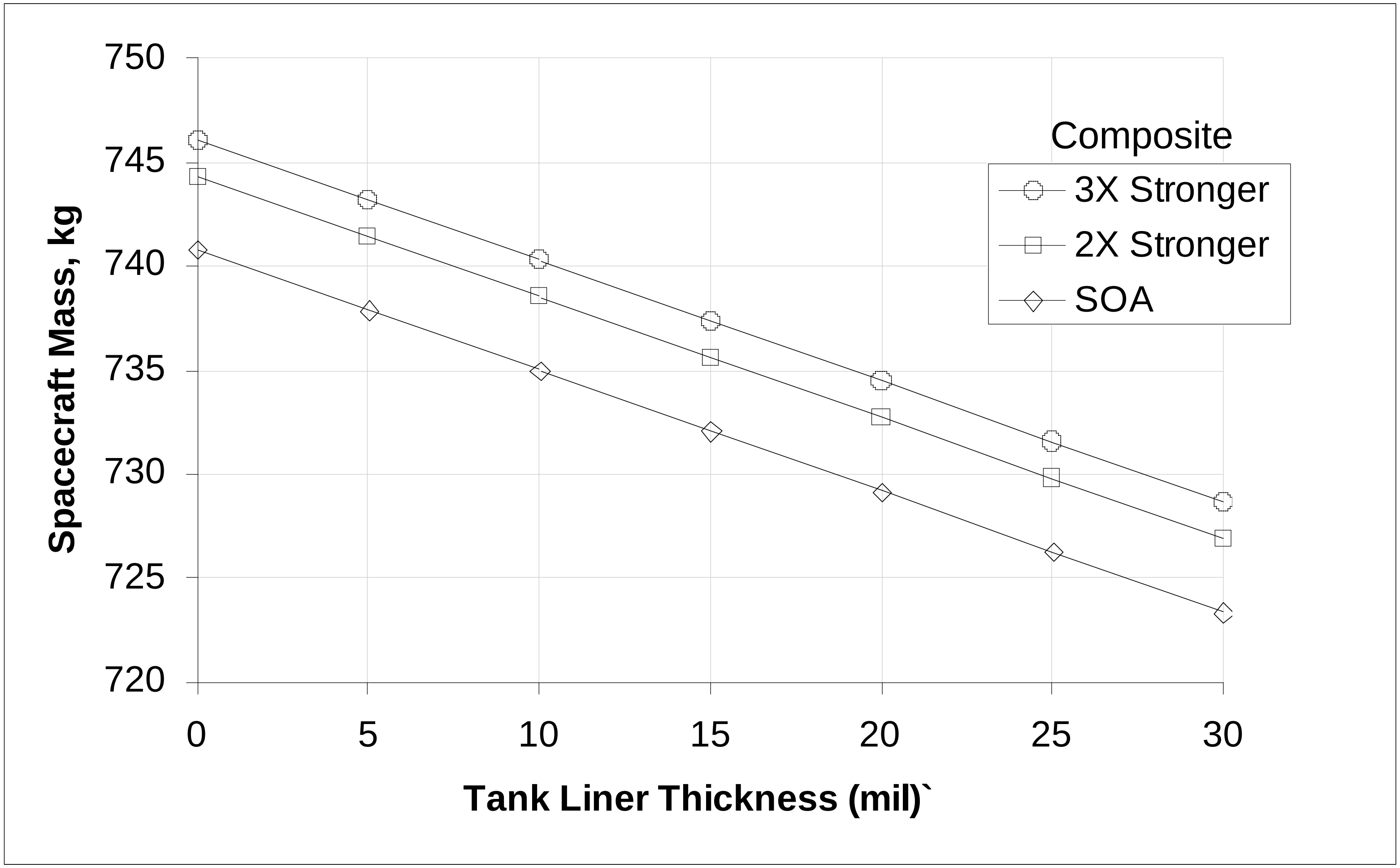
- Status
  - Study results indicate development of balanced flow metering and sensor technology could increase scientific payload mass by 10% to 56%.
- Current activities
  - Investigation of alternate technologies that would facilitate an active pressurization and MRC system to reduce propellant wet mass
  - Verifying the accuracy of balanced flow meter (BFM), tank liquid volume instrument (TLVI), optical mass gauging (OMG) and other supporting technology that would be implemented in an in-space MRC system
  - Performing a laboratory demonstration with working fluids
    - Design and test key subsystem components
    - Determine system level impacts
  - Leveraging other technology development to demonstrate and verify operational issues associated with cryogenic system mixture ratio control

ACPS Model: Overview



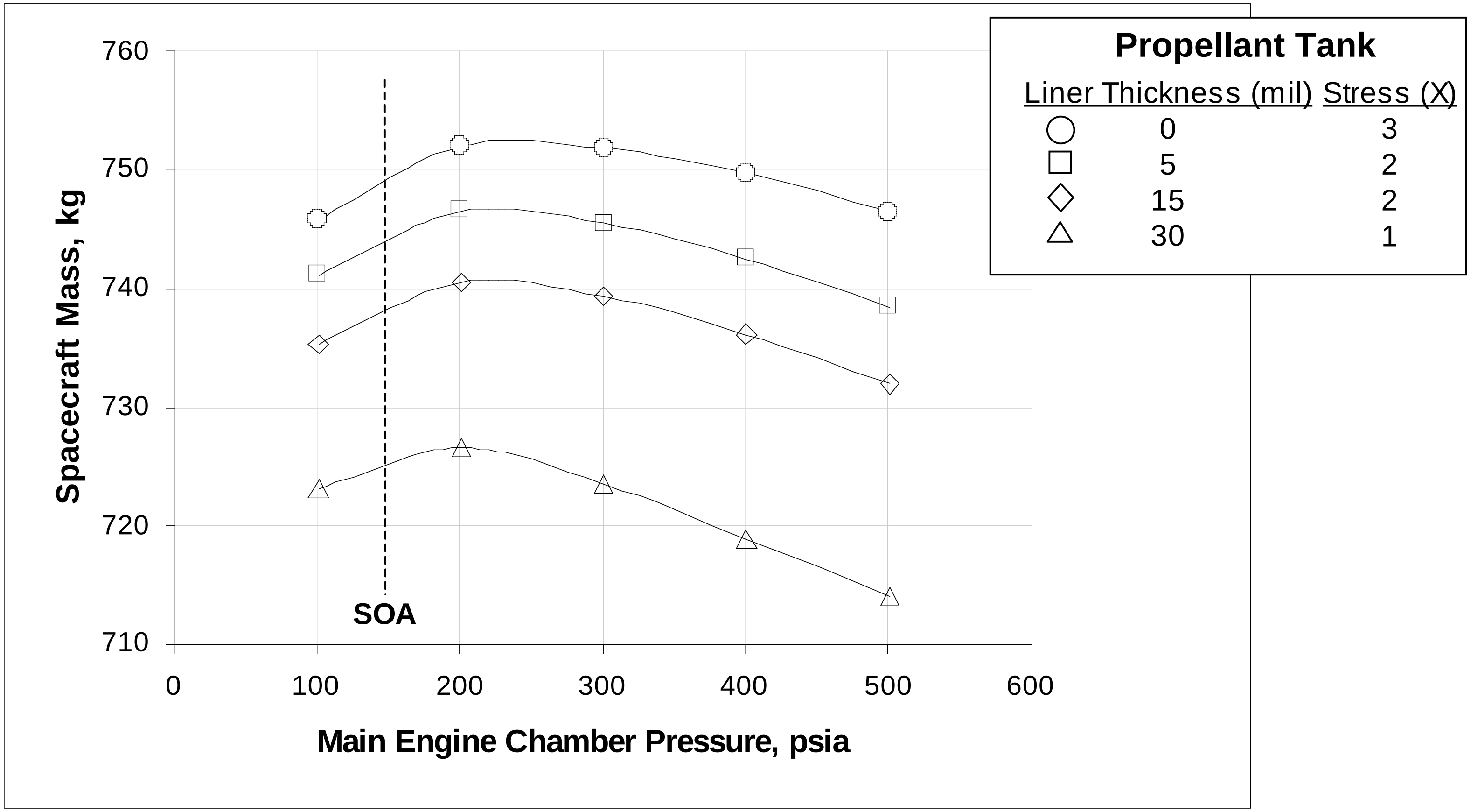
- Supports 8 different propellant combinations

Composite Propellant Tank Technology (1)



(1) New Frontiers Mission: Jupiter Polar Orbiter, VEEGA, 5.84 yr Trip Time, Mo = 1940 kg, ΔV = 2110 m/sec

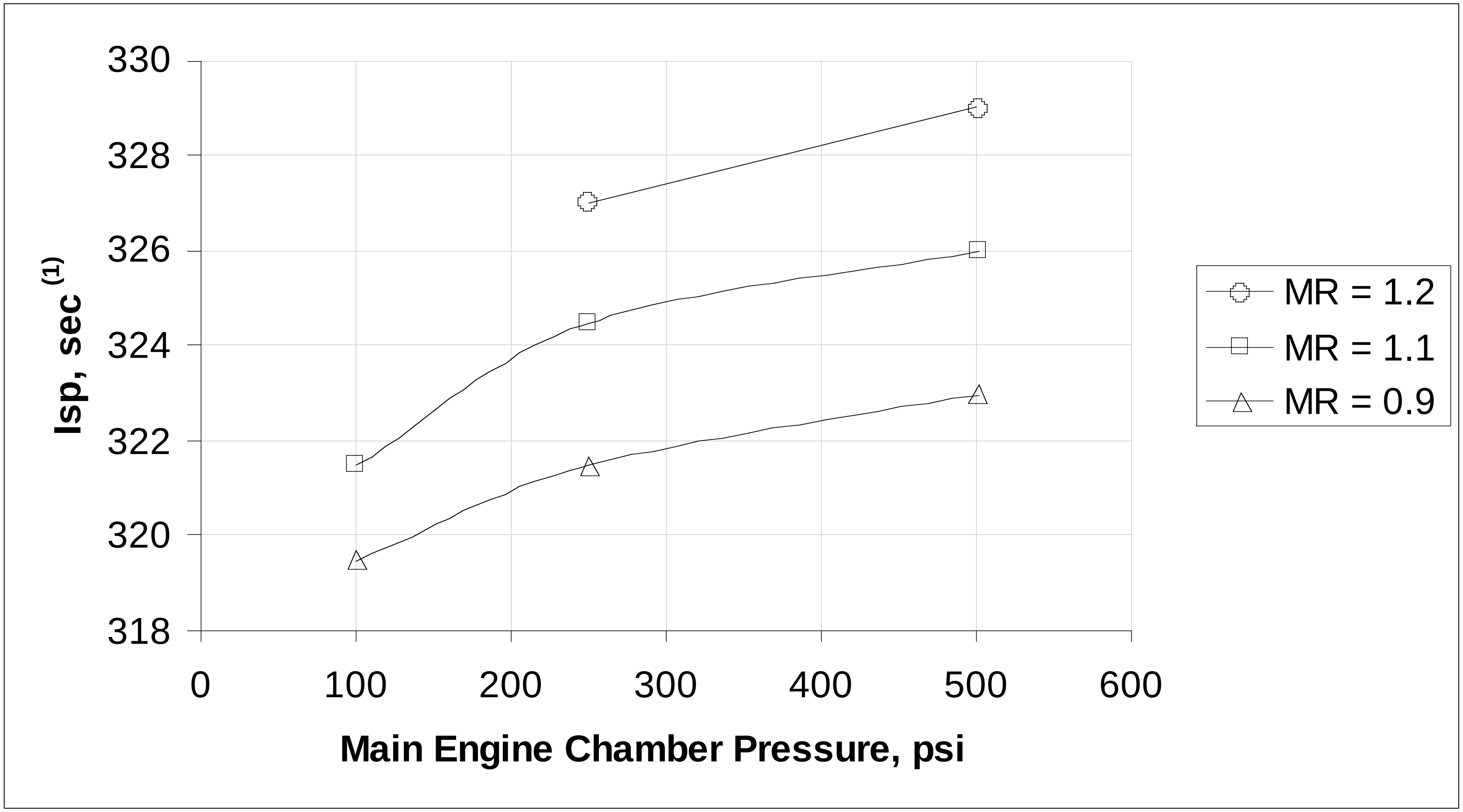
Mission Evaluation [1] – NTO/N_2H_4



- Advanced propellant tanks provide significant benefits
- The optimum Pc increases for higher strength composites
- Pc increases alone provide small benefits

(1) New Frontiers Mission: Jupiter Polar Orbiter, VEEGA, 5.84 yr Trip Time, Mo = 1940 kg, ΔV = 2110 m/sec

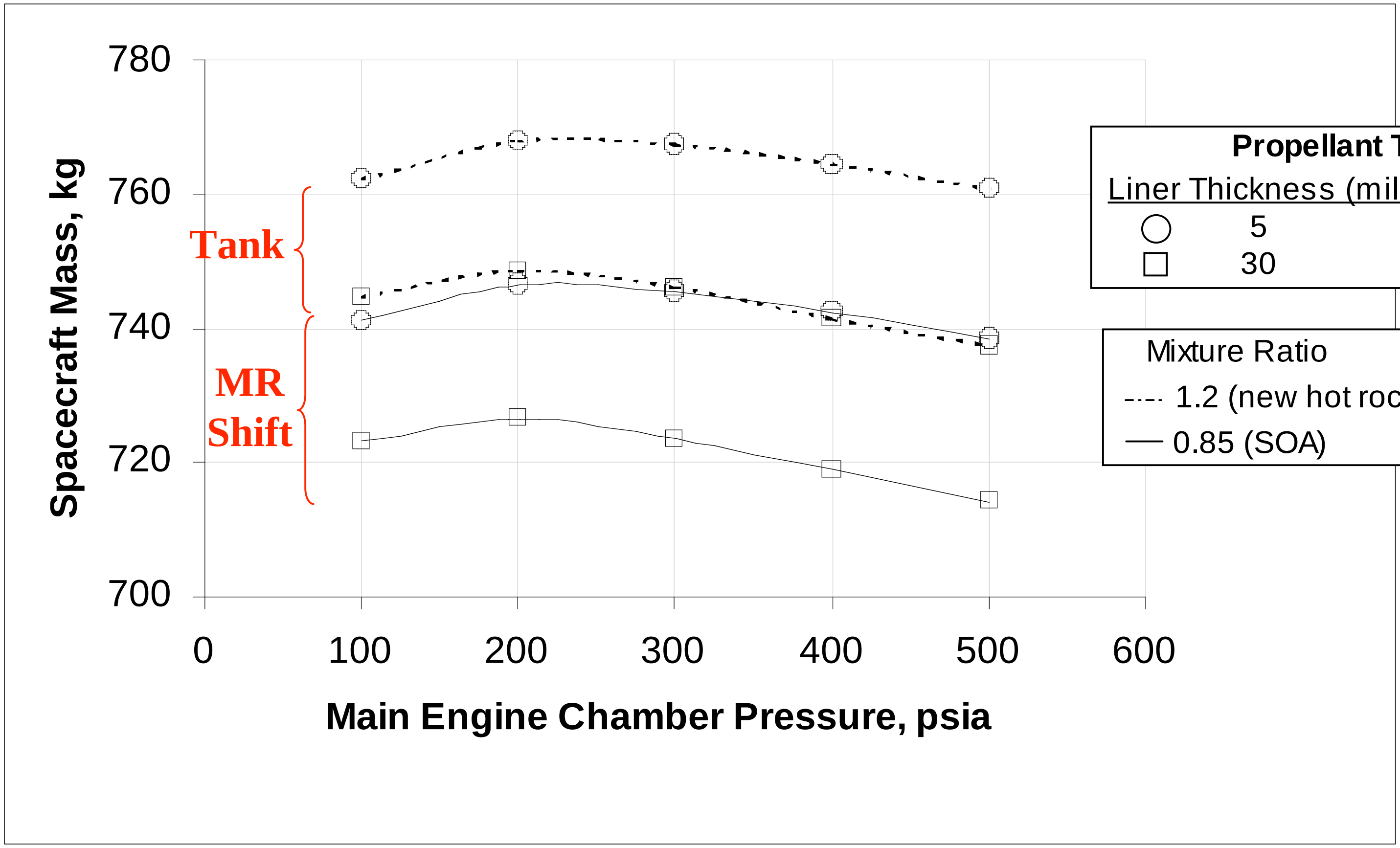
Influence of Chamber Pressure & MR Effect



Increasing either chamber pressure or mixture ratio increases the Isp of the engine (increases combustion chamber temperature as well)

(1) Data From NASA CR-195427, Vol. 1

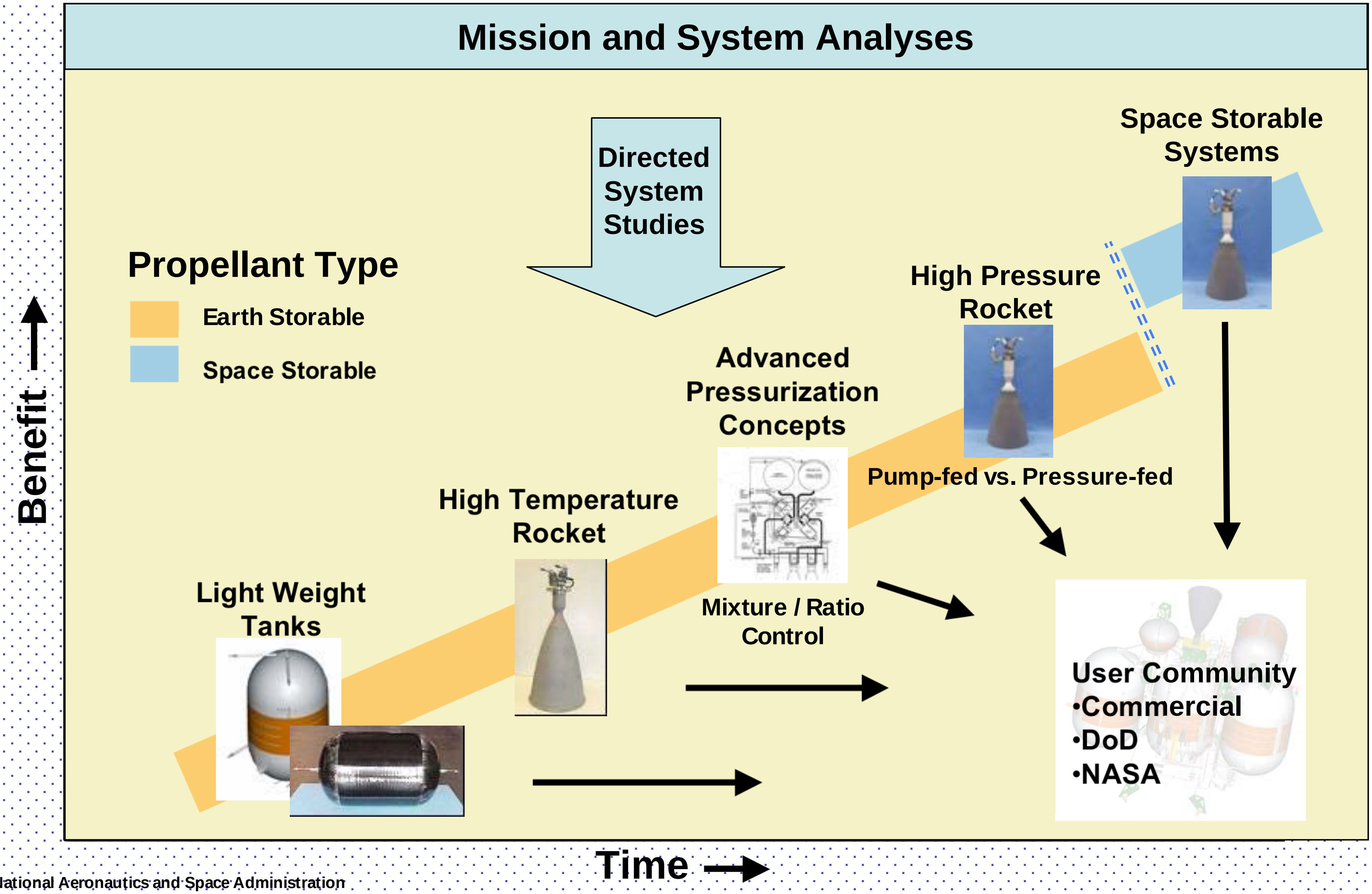
Mission Evaluation [1] – NTO/N_2H_4



- Increasing mixture ratio has a positive effect on spacecraft mass, without tank technology additions
- Combining technologies (mixture ratio & tank) can increase payload significantly

(1) New Frontiers Mission: Jupiter Polar Orbiter, VEEGA, 5.84 yr Trip Time, Mo = 1940 kg, ΔV = 2110 m/sec

Advanced Chemical Propulsion Strategy



Advanced Ionic Monopropellants

- **Ionic monopropellant assessment**
  - Experimental test series completed with 5 burns of AFM-315A propellant at MSFC
  - Assessment of impact of advanced monopropellants on SMD missions is in work

- **Motivation:**

  Hydrazine is considered the SOA in liquid monopropellants, yet there are new liquid monopropellant formulations in development with a number of improvements

  - 'Green' propellants with very low vapor pressure and far fewer ground handling concerns/costs
  - Specific impulse values 22-28% higher than hydrazine
  - Density 45% greater
  - Density-specific impulse 77% greater
  - Delta-V 74% greater
  - Lower freezing point

- **Advantages:**

  Liquid monopropellant rocket motors over bipropellant motors*****

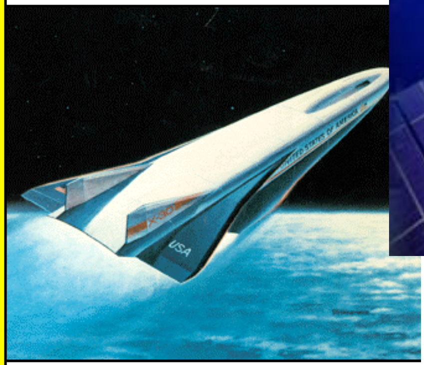
  - One propellant tank with a single feed system
  - Simplified injection – no need to worry about mixing of propellants
  - Operation is less likely to vary with ambient temperatures
  - Use of a single propellant may simplify field operations

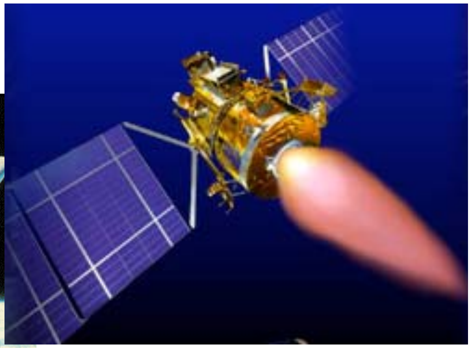
- *Altman, D, Carter, J., Penner, S., and Summerfield, M., Liquid Propellant Rockets, 1960

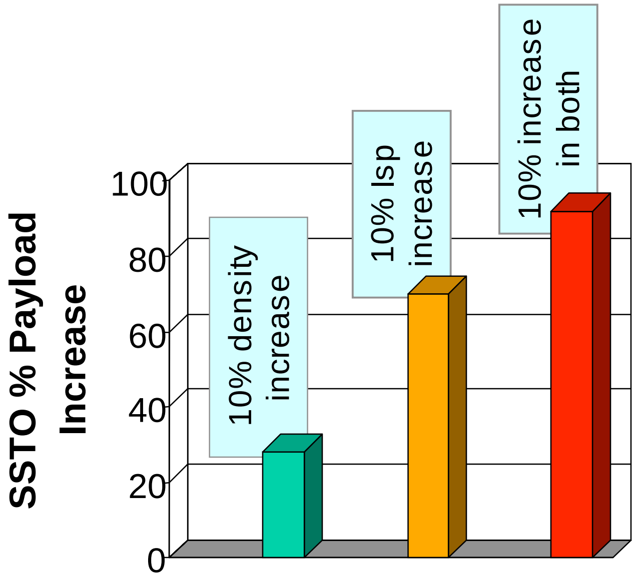
High Performance Monopropellants

Vastly increased performance with new high energy density propellants

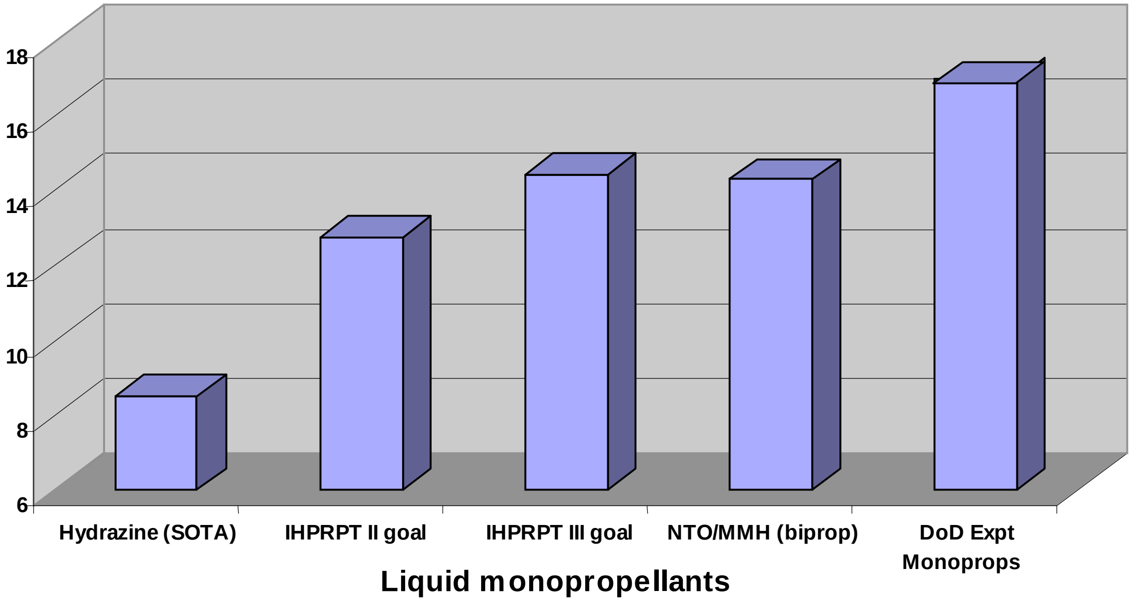
- Enabling larger payloads, smaller vehicles, and new mission capability
  - Highly reduced inert system mass compared to bipropellant
- Reducing the cost of exploring space
  - Smaller vehicle size and lower development costs
  - Low-toxicity, and vapor pressure ‘green’ propellant for lower operation cost





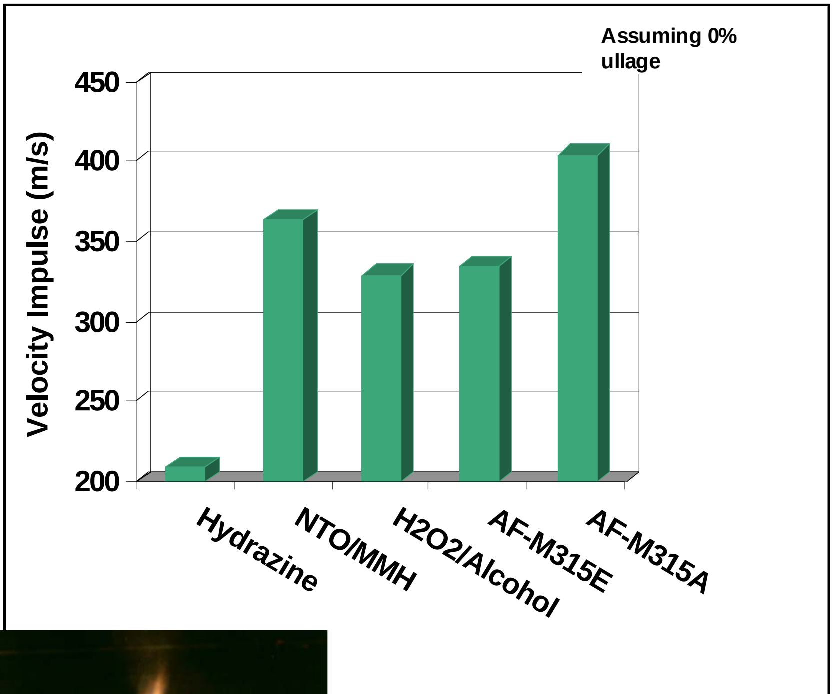


Theoretical Density Impulse (lb*sec/in3)
Isp code ran @ 50:1 expansion ratio/ 300 p.s.I. To 0.001 p.s.I.



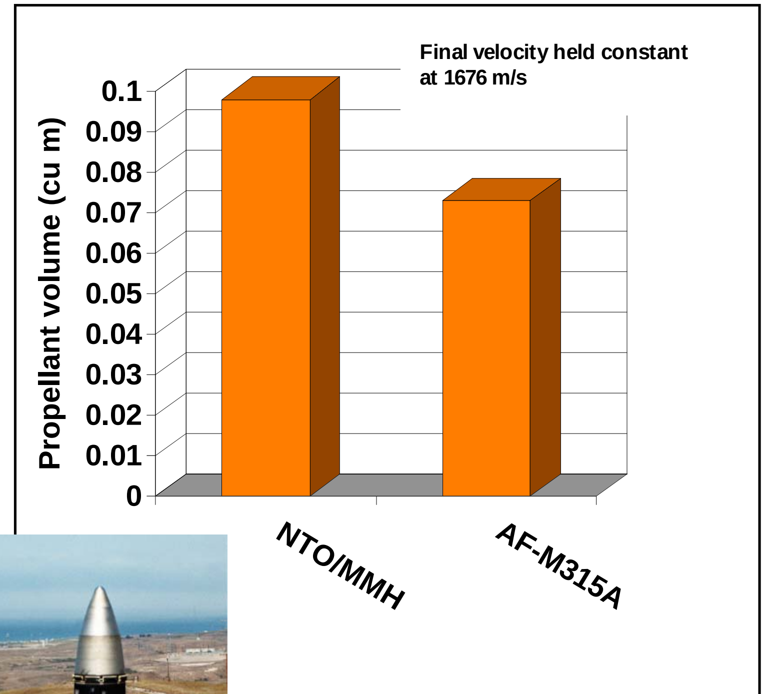
Advanced Monopropellant Performance Payoffs

Microsatellite Trade Study



- Advanced monoprop performance can even exceed that of biprops

ICBM 4th Stage Trade Study

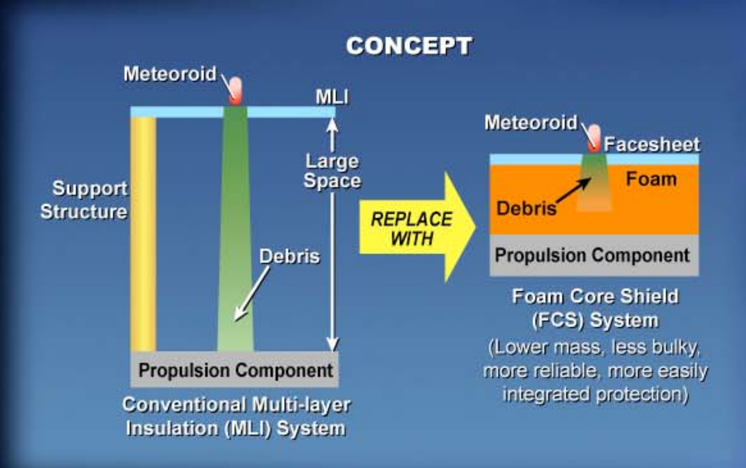


- Advanced monoprop performance allows increased range or payload over biprops

Other Lightweight and Optimized Components

Lightweight Foam Core Covers

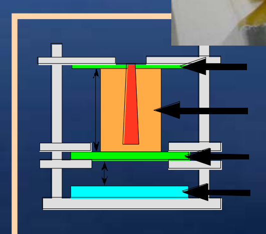
PI: NASA-JPL; Co I: ARC



Objectives

- **Minimize the dependence on and possibly replace MLI w/Foam Core Shield (FCS) System:**
  - Reduce Mass and bulk volume of installed propulsion components
  - Provide higher reliability protection against meteoroid damage
  - Provide ease of spacecraft integration

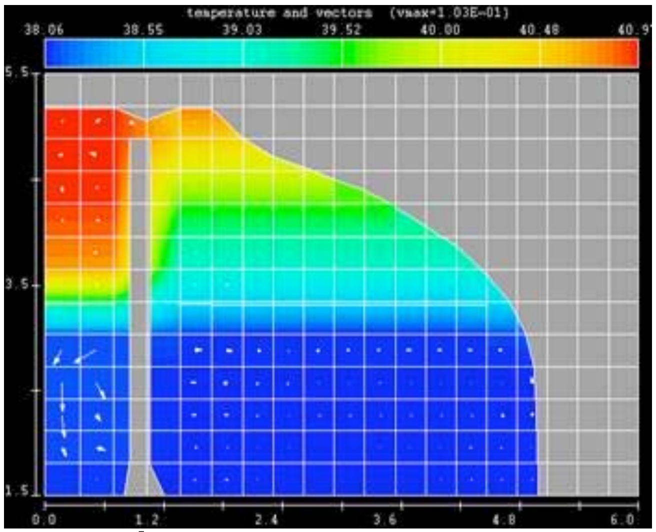
- **Ongoing / future work w/ FCS System:**
  - Velocity impact testing and evaluation
  - Thermal analysis of FCS systems
  - Database and models development to guide design of FCS systems for spacecraft components
  - FCS and MLI performance comparison
  - Demonstration of the superiority of FCS for a Pressure Line and a Tank configuration
  - Optimization and demonstration of FCS on pressure tank and line applications



Other Advanced Propellants

Cryogenic Pressure Control in Orbit

PI: NASA/MSFC; Co-I: Boeing



Products

- Anchored analytical modeling technique for application to various missions and vehicles
- Combined test & analytical capability to support virtually all future cryogenic propellant uses in orbit
- Analytical models and documentation of data

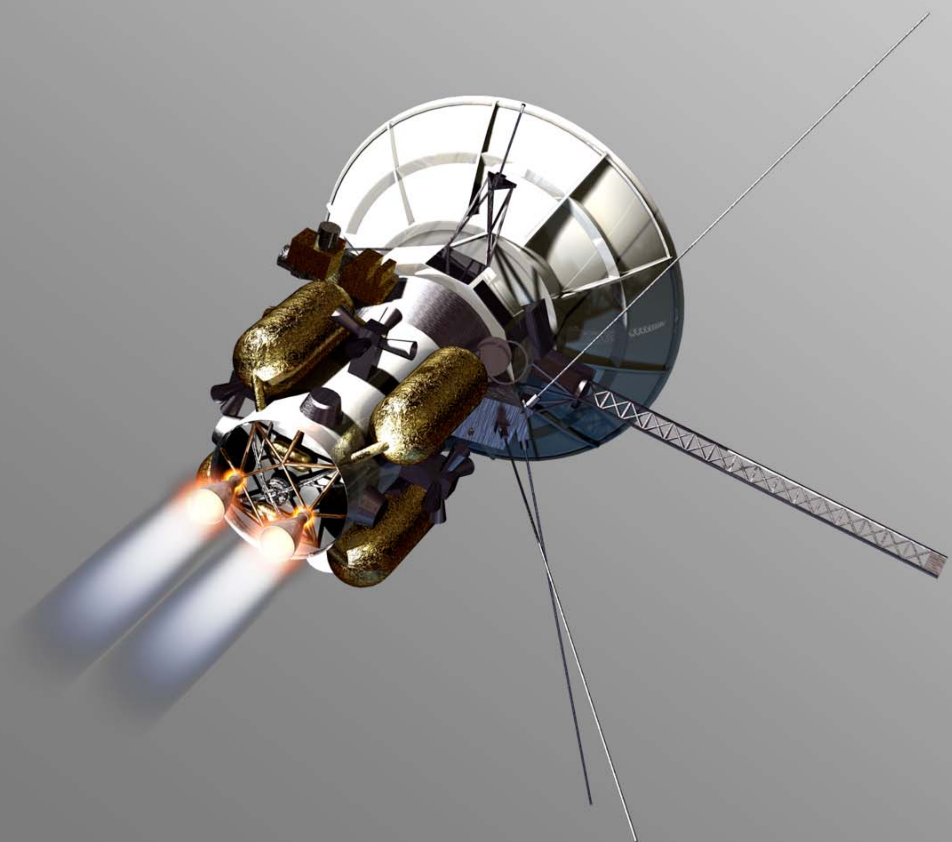
Objectives

- Develop an accurate computational thermodynamic & fluid-dynamic modeling capability for simulation of advanced cryogenic storage tanks in space.
- Techniques for pressure control within +/- 0.5 psi control band
- Demonstrate concept verification with normal gravity testing & analytical extrapolation to orbital environments

Benefits

- Deletion of APS for settling/venting, mission planning simplification
- Cross-cutting application to orbital cryo propulsion & storage
- Minimizes dependence on orbital experimentation

For additional information on **Advanced Chemical Propulsion** within the In-Space Propulsion Technology Program, please contact:



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BACKUP CHARTS

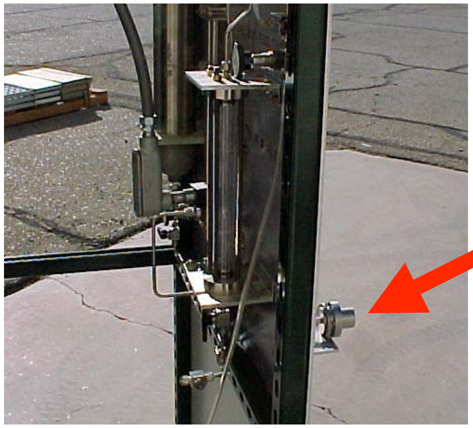
Monopropellant for Large Engines - Concept Feasibility

Objective:
- Establish feasibility of using emerging class of high performance monopropellant for large launch engines

Payoff:
New monopropellant-based propulsion approach with,
- Highly reduced inert system mass compared to bipropellant
- Smaller vehicle size and lower development costs.

Potential Performance:
New, earth-storable monopropellant propulsion for,
- High performance; DIsp> 25% Increase over NTO/MMH
- Low-toxicity, "green" propellant for lower operation cost

Milestones:
- Quality Function Deployment analysis of propellant
  Construct propellant injector and combustion test H/W
  Propellant safety, hazard, ignition/combustion tests



Monopropellant ignition test H/W equipped with PDFM feed system and quad impinging jet injector (also, full-cone spray injector)

Status:
Completed and delivered Quality Function Deployment based assessment of new propellant replacement technology
- Ignition test hardware components production/assembly completed
- Propellant candidate formulation and characterization in progress

Collaborations:
USAF AFRL (Edwards AFB CA)
(Tom Hawkins, USAF/AFRL 661-275-5449)

Points of Contact:
John Blevins/ MSFC, Greg Drake MSFC

<u>MSFC Trade Study</u>

- **AF-M315 propellant in TSTO (2nd stage reaches ISS)**
- **Reduced tankage mass drives performance increase**
- **Advanced propellant provides TSTO with greater payload**